

Table 13

Thickness of Free Layer, t(F) (nm)	Thickness of Ferromagnetic Layer A, t(P) (nm)	Resistance Change Rate, $\Delta R/R$ (%)	$(t(F) - t(P))/t(F)$
4.5	1	4.7	0.78
4.5	1.5	6.9	0.67
4.5	2	7.1	0.56
4.5	3	7.9	0.33
4.5	4	7.7	0.11
4.5	5	7.3	-0.11
4.5	6	6.8	-0.33
4.5	7	5.9	-0.66

The free layer is of CoFe. The ferromagnetic layers A and B are both of CoFe. The thickness of the ferromagnetic layer B is 3 nm.

For the protective film, used is any of metals of Ta, Nb, Zr, Cr, Hf, Ti, Mo, W and the like, or their alloys, or their oxides, nitrides, etc. Preferred are high-resistance protective films of metal oxides or nitrides, for example, NiFe oxides, aluminium oxides, tantalum oxides and others, as giving high resistance change rates. Regarding its thickness, it is desirable that the protective film is as thin as possible and has a thickness of from 0.3 to 4 nanometers. This is because, as will be mentioned hereunder, such a thin protective film is easy to remove through etching for forming electrodes and longitudinal bias layers. As the protective layer, also usable are single-layered or laminated films of simple noble metals such as Ag, Au, Ru, Ir, Cu, Pt, Pd, Re and others, or

of their alloys. For example, for the free layer of CoFe, usable are protective layers of Cu/Ru, Cu, Au, Cu alloys, etc.; for the free layer of NiFe, usable are protective layers of Ag, Ru, Ru/Ag, Ru/Cu, Cu, etc. Over the protective film of oxides, nitrides or noble metals, an additional, high-resistance protective film of Ta or the like may be optionally formed.

For making the magnetization direction of the pinned magnetic layer perpendicular to that of the free layer, for example, employable is the following method. Where the antiferromagnetic layer 143 is of a γ -Mn-based, Mn-rich alloy such as IrMn, RhMn, RhRuMn or the like, the deposition of the constituent layers of the spin valve film to the antiferromagnetically coupling layer 1442 is carried out in a magnetic field as applied in the direction of the width of the spin valve device to be produced, or that is, in the height direction, and thereafter the resulting layered structure is subjected to thermal treatment for unifying the coupling bias magnetic field due to the antiferromagnetic layer 143 in the height direction. The thermal treatment for unifying the coupling bias magnetic field in the height direction may be carried out immediately after the formation of the antiferromagnetic layer B. However, since the antiferromagnetically coupling layer of Ru or the like is more resistant to oxidation, it is more desirable that the thermal

treatment is effected after the formation of the coupling layer 1442. Preferably, the thermal treatment is effected still in vacuum, or that is, without leaking the vacuum for the previous deposition, at a temperature higher than Tb and for a short period of time, more preferably within at most 10 minutes, in a magnetic field in which the ferromagnetic layer B could be completely saturated. For example, for IrMn having Tb of 300°C, the thermal treatment may be effected at 350°C for 1 minute or so.

Next, still in vacuum, a magnetic field is applied in the direction of the track width of the spin valve device being formed, at least during the formation of the free layer, and thereafter, the remaining films of the spin valve device are formed. The same shall apply to the case where the antiferromagnetic layer is of a ordered alloy of PtMn or NiMn. For this case, however, the process will somewhat differ from that for the case of the γ -Mn-based antiferromagnetic layer noted above. In this case, the deposition step up to the formation of the antiferromagnetic layer B does not always require a magnetic field, but the thermal treatment after the step must be effected at high temperatures of at least 200°C, preferably falling between 270 and 350°C, for a few hours, preferably for 1 to 20 hours. After the thermal treatment, a magnetic field is applied during the step of forming the free layer and thereafter the remaining layers of the spin valve